HOMOGENEOUS NMR LINE SHIFT INDUCED BY MAGNETIC DOPING IN A SUPERCONDUCTOR

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It is shown theoretically that a uniform conduction electron spin polarization, induced by magnetic doping, arises in a superconducting state. Measurements of the corresponding Knight shift enable one to determine the sign of the s–f exchange constant.

The magnitude and sign of the s–f exchange interaction constant are important characteristics which reflect strength and type (ferro- or antiferromagnetic) of the coupling of conduction electrons (CE) and doped localized spins (LS) in dilute alloys.

Large inhomogeneous broadening and small value of the NMR line shift induced by doped LS in a normal metal [1] make it difficult to determine the sign of the exchange integral J_{sf} via NMR. In the present letter we would like to show that in a superconductor with paramagnetic doping there arises a large homogeneous NMR line shift, the measurements of which may provide unambiguous information about the sign of J_{sf}.

The NMR frequency shift $K^{\mathrm{s}}(\boldsymbol{r}_i)$ in the site $\boldsymbol{r}_i$ is determined by the non-local spin susceptibility of CE $\chi^{\mathrm{s}}(r_{ij})$:

$$K^{\mathrm{s}}(\boldsymbol{r}_i) = K^{\mathrm{n}}\left(\chi^{\mathrm{s}} - J_{\mathrm{sf}}\,(\chi^{\mathrm{LS}}/2g\mu_{\mathrm{B}}^2) \times \sum_j{}' \chi^{\mathrm{s}}(|\boldsymbol{r}_i - \boldsymbol{r}_j|)\right)\Big/\chi^{\mathrm{n}}\,, \tag{1}$$

where K^{n} is the Knight shift in a normal metal without doping; $\chi^{\mathrm{S}}(T)$ and χ^{n} are the homogeneous CE-spin susceptibilities of a superconductor and a normal metal [2]; $\chi^{\mathrm{LS}}(T)$ is the paramagnetic susceptibility per single doped LS; g is the LS g factor; μ_{B} is the Bohr magneton; the primed sum means that the vector $\boldsymbol{r}_j$ spans over the lattice sites, occupied by LS.

The susceptibility $\chi^{\mathrm{s}}(r)$ consists of the susceptibility of the normal CE

$$\chi^{\mathrm{n}}(r) \sim (a/r)^3 \cos 2k_{\mathrm{F}} r\,,$$

oscillating with distance r (see, for example, ref. [3]) and the non-oscillating long-range addition

$$\Delta\chi^{\mathrm{s}}(r) \sim (a^3/\xi^2 r)\exp(-r/\xi)$$

which arises only in a superconducting state [4] (k_{F} is the Fermi wave-number, ξ the coherence length of a "dirty" superconductor and a the lattice spacing).

The electron polarization, determined by the susceptibility $\chi^{\mathrm{n}}(r)$, has strong spatial dispersion and, as has been shown by Walstedt and Walker [1], leads to an inhomogeneous broadening ΔH of the main line and to a slight line shift δ_{n}:

$$\gamma_{\mathrm{n}}\Delta H \equiv \Gamma_{\mathrm{n}} = (cK^{\mathrm{n}}J_{\mathrm{sf}}\chi^{\mathrm{LS}}/6g\mu_{\mathrm{B}}^2)\exp(-1.59 r_{\mathrm{av}}/l), \tag{2}$$

$$\delta_{\mathrm{n}} = (\mathrm{const})J_{\mathrm{sf}}(\chi^{\mathrm{n}})^{-1} \sum_{|\boldsymbol{r}_j|>r_{\mathrm{c}}}{}' \chi^{\mathrm{n}}(r_j) \lesssim 0.1\Gamma_{\mathrm{n}}\,. \tag{3}$$

Formula (2) coincides with the corresponding formula